An evaluation of OZONE INJURY to PINES in the SOUTHERN SIERRA NEVADA

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SUMMARY

The Forest Service has been assessing the impact of oxidant air pollution (ozone) on ponderosa and Jeffrey pines in the Sierra Nevada since 1974. Assessment activities have included:

1. Conducting ozone injury ground surveys.

2. Maintaining ozone injury trend plots.

3. Monitoring ambient ozone levels.

GROUND SURVEY

In 1977 a cooperative ozone injury survey was conducted on the Sierra and Sequoia National Forests. The survey was designed to identify sites where ozone symptoms were present or absent on pines, and to determine the actual extent of oxidant injury. The results showed that on 68 percent of the plots at least one tree out of 10 had ozone symptoms. The worst injury found was considered to be at a "moderate" level and accounted for less than 6 percent of the plots. The most seriously-affected plots were all located between 4000 and 7000 feet (1220 and 2135 meters) on front range mountains adjacent to the San Joaquin Valley or along major river drainages.

TREND PLOTS

Two trend plots, located approximately 50 miles east of Fresno, were visited and rated for injury each year since 1974. Neither plot demonstrated any consistent increase or decrease in smog injury ratings between 1974 and 1978.

OZONE MONITORING

During 1977 the FIDM Staff monitored ambient ozone levels at Whitaker's Forest, Park Ridge Lookout, and Mountain Home State Forest. Ozone doses and exposure times in excess of the Federal Standard (eight parts per hundred million) were greatest at Whitaker's Forest. Comparison of August ozone readings between 1976 and 1977 at Whitaker's shows an increase greater than two pphm in the average daily maximum ozone level. Ozone data collected from Shaver Lake south to Mountain Home suggest that day-to-day fluctuations and overall trends in ozone levels are similar throughout this area and are not just peculiar to Whitaker's Forest.

CONCLUSIONS AND RECOMMENDATIONS

Smog symptoms are common and widespread in much of the southern Sierra Nevada, but the presence of ozone is not currently causing moderate or severe injury to pines on a forest-wide basis. Localized areas with moderately-injured pines do, however, exist, and ozone-sensitive trees

will suffer continued injury if past seasonal ozone levels reoccur. Ozone concentrations high enough to produce chlorotic mottle on pines have been measured over a 70-mile portion of the western slopes of the southern Sierra Nevada, but, since 1974, trend plots have not shown any obvious trends in the level of ozone injury.

Based on the information from these studies and because of questions still unanswered, the following recommendations are made:

1) Conduct a Pest Damage Inventory (PDI) on the Sierra and Sequoia National Forests.

2) Continue to monitor ozone levels at selected forest locations, with at least one permanent and continuous monitoring site.

3) Establish additional injury trend plots to assess smog effects under a variety of sites, stand characteristics, and ozone concentrations.

INTRODUCTION

Ozone injury symptoms on pines in the Sierra Nevada Mountains of central California were first reported in 1971 (5). At that time the serious impact of air pollution on ponderosa and Jeffrey pines in southern California was well known and documented; tree mortality over a two-year period had exceeded 8 percent on some sites in the San Bernardino Mountain forests (3,4). As a result, the Forest Service has been concerned about the current status and potential threat of ozone injury in the National Forests that border the San Joaquin Valley air basin.

In 1974 the Forest Insect and Disease Management Staff (FIDM) began to describe and assess the air pollution situation in the southern Sierra Nevada. Evaluation efforts have included ozone injury ground surveys, ozone injury trend plots, and ozone dose monitoring.

OZONE INJURY GROUND SURVEY

Initial roadside surveys in 1974 identified sites where ozone symptoms were present, but did not rate the level of injury or record the presence of other insect or disease pests (7). During September and October 1977, a more comprehensive ground survey was conducted by Forest and FIDM personnel on the Sierra and Sequoia National Forests (see Figure 2, page 7).

The survey was designed to identify sites where ozone symptoms were present or absent on ponderosa and Jeffrey pines, to identify any other pests affecting these pines, and to determine the actual extent of ozone injury. Only these two pine species were included because they are the most sensitive ozone injury indicator conifers in California.

Ozone symptoms include the characteristic chlorotic mottle on the foliage of affected pines in addition to reduced needle length and reduced needle retention. Usually ozone symptoms appear first on the oldest needles and lowest branches, and with increasing injury, progress to the younger needles and upper branches. The severity of ozone impact determines whether a tree has been injured or damaged. We distinguish between injury and damage in the following way: injury includes any abnormal changes in the appearance or function of a tree, whereas damage involves a measurable decrease in growth or economic value of a tree. We did not collect growth data during the survey, and, therefore, our comments are restricted to levels of visible oxidant injury and not to measured amounts of tree damage.

METHODS

In preparation for the survey, potential plot sites were systematically located on topographic maps wherever roads or trails intersected 4000, 5000, 6000, 7000, and 8000 foot (1220, 1525, 1830, 2135, and 2440 meter) contour lines. These elevational limits were used because the majority of commercial pine stands in the southern Sierra Nevada are found between 4000 and 8000 feet. Plot sites were then visited on the ground and considered valid if ten ponderosa and/or Jeffrey pines were found within an area one chain (20 meters) by six chains (121 meters) on each side of and parallel to the road or trail. The near edge of each plot was separated from the roadside influence by one-half chain (10 meters). Four hundred seventy-four sites were visited, and from these, 242 valid plots were established. Within each plot various site and tree characteristics were observed or measured. Some of the important data collected included the level of ozone injury, the other pests present on each of the ten trees, the distance from the plot to the suspected metropolitan pollutant source, and the plot elevation. Pest data were collected to avoid confusing other abiotic or biotic symptoms with ozone injury.

Ozone symptoms were evaluated and rated by examining branches from the lower crown of each tree. The scoring system used is described in Table 1. It is based on the severity of chlorotic mottle present on pine foliage. Pines with symptoms were given a score between 0 and 4, the number indicating how many years of retained needles were healthy or free of mottle. Trees with no symptoms and trees with symptoms on fifth year or older needles received scores of 4. The 10 individual tree scores were averaged to yield a plot score, and the overall injury for each plot was described as listed under "Extent of Injury" in Table 1.

TABLE 1. FIDM ozone injury scoring system for pines.

INDIVIDUAL TREE SCORE	YOUNGEST NEEDLES WITH SYMPTOMS	AVERAGE PLOT SCORE	EXTENT OF INJURY
0	Current Year	0 - 0.9	Very Severe
1	Second Year	1.0 - 1.9	Severe
2	Third Year	2.0 - 2.9	Moderate
3	Fourth Year	3.0 - 3.9	Slight
4+	Fifth & Older	4.0+	Very Slight
4	None	4.0	No Symptoms

Rechecked Plots. Twenty-four plots (approximately 10 percent of the total) were revisited by a plant pathologist and rated for smog injury to ensure that the survey crews were consistent and accurate. No major differences that would change the overall plot ratings were found.

RESULTS AND DISCUSSION

The results for both Forests are combined in Table 2 and show that on 68 percent of the plots at least one tree out of ten had symptoms of oxidant injury. Forty-two percent of the plots had Very Slight injury or No Symptoms, 52 percent had Slight injury and only 6 percent had Moderate scores. No plots had ratings worse than Moderate, and plots with Moderate injury were found at all elevations except 8000 feet.

TABLE 2. Plot ratings for ozone injury on the Sierra and Sequoia National Forests, 1977.

	NUMBER OF PLOTS BY OZONE INJURY RATING				
ELEVATION (Feet)	MODERATE (2.0-2.9)	SLIGHT (3.0-3.9)	VERY SLIGHT (4.0+)	NO SYMPTOMS (4.0)	TOTAL
4000	3	21	3	12	39
5000	5	42	3	15	65
6000	4	34	8	20	66
7000	2	26	7	11	46
8000	0	4	3	19	26
TOTAL (Percent)	14 (5.8)	127 (52.5)	24 (9.9)	77 (31.8)	242 ---

Separate results for the two National Forests are included in Tables 3 and 4. Forty percent of the survey plots on the Sequoia National Forest had no symptoms at all compared to 22 percent on the Sierra National Forest. Whether this comparison holds true for the Forests as a whole is not known.

Although smog symptoms were found on ponderosa and Jeffrey pines throughout most of the Sierra and Sequoia National Forests, the exact

TABLE 3. Plot ratings for ozone injury on the Sierra National Forest, 1977.

ELEVATION (Feet)	NUMBER OF PLOTS BY OZONE INJURY RATING				
	MODERATE (2.0-2.9)	SLIGHT (3.0-3.9)	VERY SLIGHT (4.0+)	NO SYMPTOMS (4.0)	TOTAL
4000	2	21	2	7	32
5000	3	26	2	5	36
6000	3	11	4	6	24
7000	1	7	2	3	13
8000	0	0	2	4	6
TOTAL	9	65	12	25	111
(Percent)	(8.1)	(58.6)	(10.8)	(22.5)	---

TABLE 4. Plot ratings for ozone injury on the Sequoia National Forest, 1977.

ELEVATION (Feet)	NUMBER OF PLOTS BY OZONE INJURY RATING				
	MODERATE (2.0-2.9)	SLIGHT (3.0-3.9)	VERY SLIGHT (4.0+)	NO SYMPTOMS (4.0)	TOTAL
4000	1	0	1	5	7
5000	2	16	1	10	29
6000	1	23	4	14	42
7000	1	19	5	8	33
8000	0	4	1	15	20
TOTAL	5	62	12	52	131
(Percent)	(3.8)	(47.3)	(9.2)	(39.7)	---

level of damage being done to these trees is unknown. In our estimation trees with symptoms on fourth-year or older needles (Slight, Very Slight, and No Symptom ratings) are probably not suffering appreciable growth loss, and these three categories account for about 94 percent of the plots. The remaining 6 percent of the plots were rated to have Moderate injury. These were plots with trees that, on the average, had ozone symptoms on third-year and older needles, or had at least two years of unaffected needles. Normally, between 60 and 80 percent of the total photosynthetic activity of ponderosa pines lies with the first and second-year needles (1,2). It is possible then, that pines with smog injury on third-year and older needles are suffering some growth reduction.

Although none of the survey plots was rated to have worse than Moderate injury, several points should be kept in mind. Plot scores are the averages for 10 trees, and pines vary greatly in their sensitivity to smog. Within some Moderate and even Slight injury-rated plots there were individual trees with smog symptoms on second-year needles and with only two years of needle retention. These trees, although few in number (less than 3 percent of the total), are obviously growing under stress. Table 5 shows the distribution of ozone injury scores of individual trees in the survey plots. A total of 18.9 percent of the trees over the entire survey area showed ozone injury symptoms.

TABLE 5. The percentage of individual ponderosa and Jeffrey pines by ozone injury rating, Sierra and Sequoia National Forests, 1977. (Total trees = 2420).

TREE RATING		PERCENT TREES
No Symptoms	(4)	81.1
Very Slight	(4+)	3.6
Slight	(3)	7.4
Moderate	(2)	5.1
Severe	(1)	2.7
Very Severe	(0)	0.01

Plot Locations. The ozone injury ratings and locations of the plots were placed on a map of the survey area. Figure 2 was drawn from this map; it shows the Forest boundaries, the survey area between 4000 and 8000 feet (1220 and 2440 meters) elevation, the major river drainages, and the location of each plot, color-coded to indicate

the severity of injury. Most plots with ozone symptoms and all of the Moderate injury plots were located on the front range mountains adjacent to the San Joaquin Valley, or along the major river drainages. Moderate injury-rated plots were not concentrated in any one area, but were distributed from the far northern to the far southern boundaries of the survey area. Pines with smog symptoms were found more than 60 miles (97 kilometers) from the nearest suspected source of ozone.

Associated Insect and Disease Pests. The insects most frequently observed on the surveyed pines were aphids (Cinara spp.) and the pine needle scale (Chionaspis pinifoliae). Dwarf mistletoe (Arceuthobium campylopodum) and Elytroderma needle disease (Elytroderma deformans) were the most commonly-encountered tree diseases.

This survey was not designed to determine if there are any relationships or interactions between insects or diseases and ozone injury, but we are aware that such situations may exist. Ozone-injured pines have been reported to be more susceptible to bark beetle attack than healthy pines (6). Also, the survey was conducted during the second year of a severe State-wide drought, and we are unable to determine what effects this drought may have had on the amount of smog injury present.

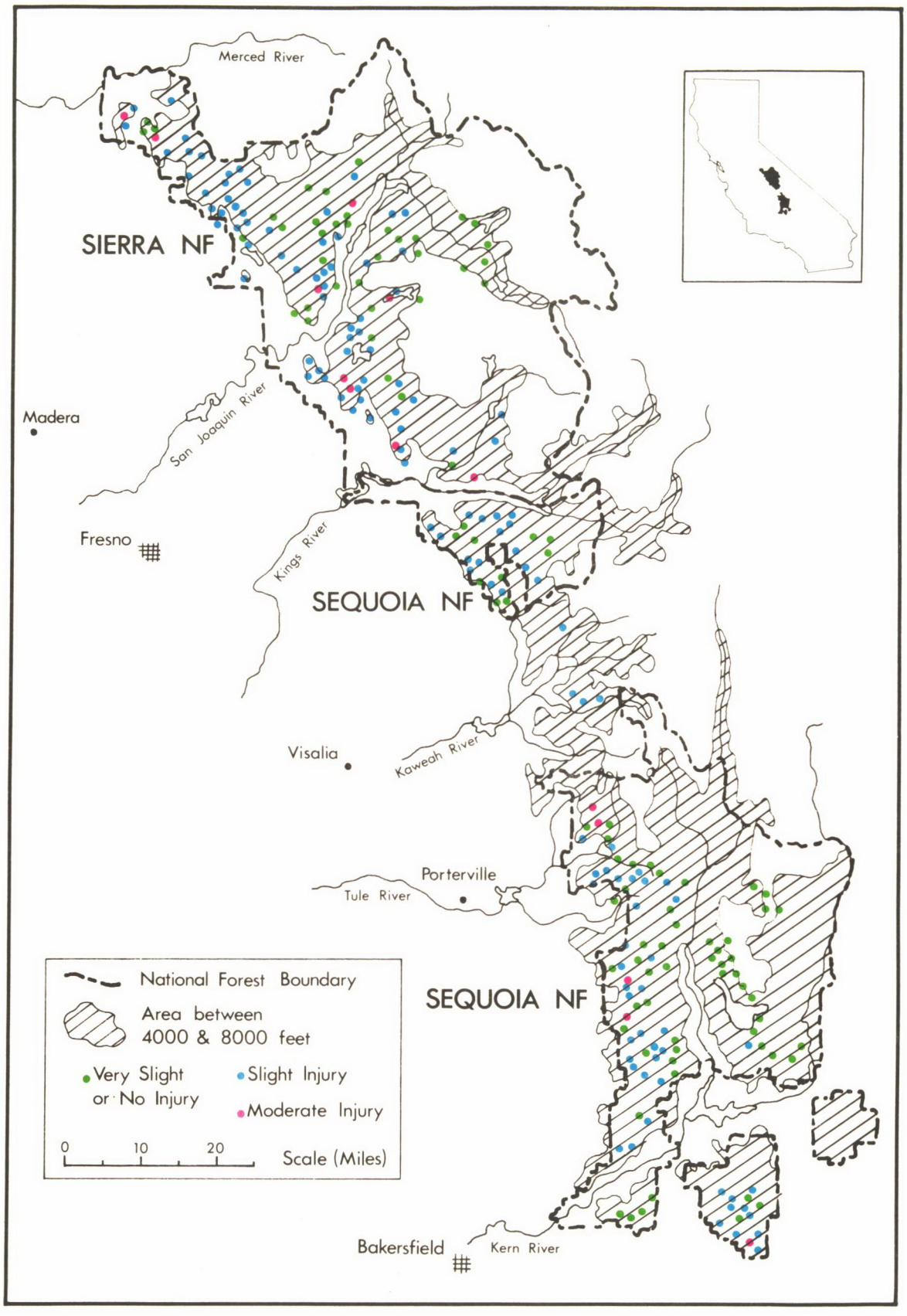

FIGURE 2. Locations and injury ratings of ozone injury survey plots on the Sierra and Sequoia National Forests, 1977.

OZONE INJURY TREND PLOTS

Two trend plots were established on the Sequoia National Forest in 1974. They were placed just west of the Grant Grove section of Kings Canyon National Park, and represent some of the most severely-affected ponderosa pine stands on the Forest (Figure 3). The plots were located 8 miles (13 kilometers) apart on Pine Ridge at 4500 feet (1370 meters), and on a ridge between Dry and Eshom Creeks at 4800 feet (1460 meters).

METHODS

All ponderosa pines larger than 4 inches (10 centimeters) d.b.h. were sampled within each 0.5 acre (0.2 hectare) plot. Data were collected on several tree and site variables, and each tree was

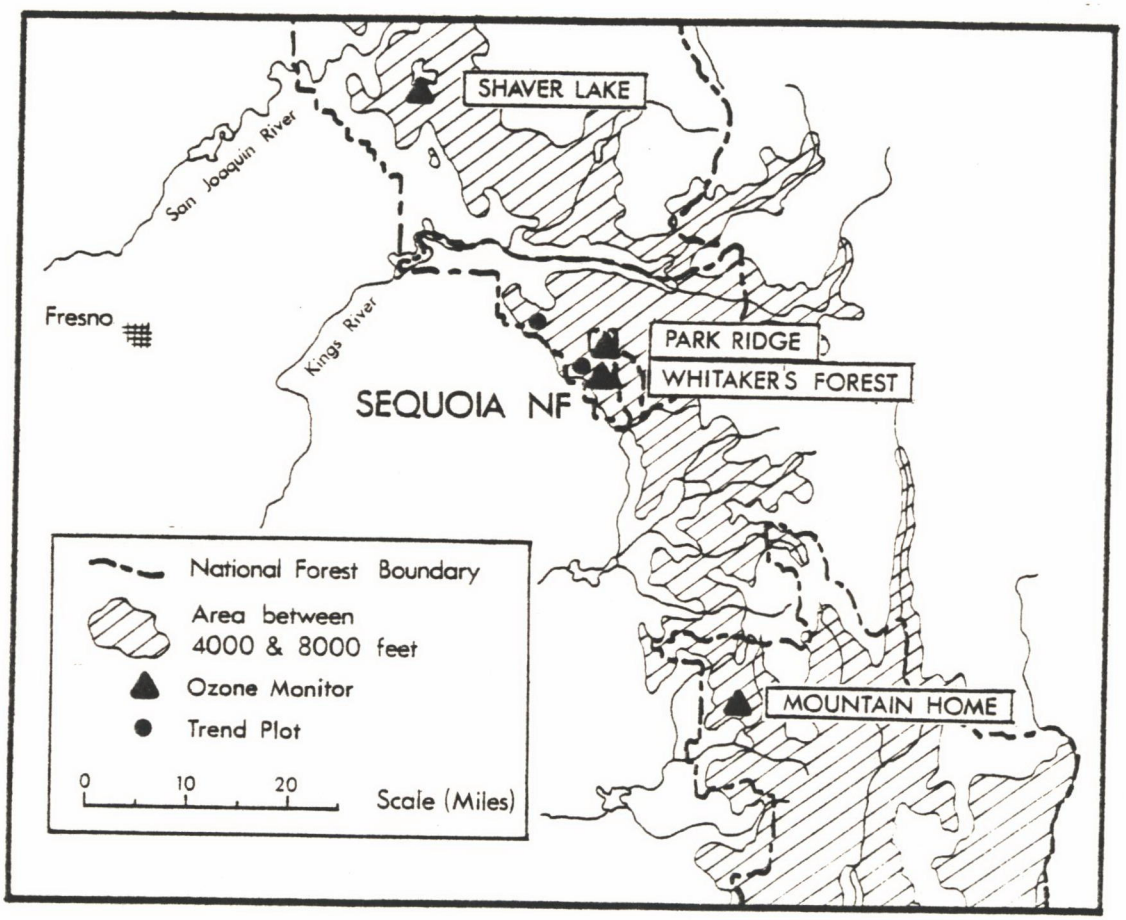

FIGURE 3. Locations of ozone injury trend plots and ozone monitors on the Sierra and Sequoia National Forests, 1977.

rated for ozone injury according to the FIDM system. The plots were revisited each year in the fall, and the trees were again rated to detect changes in ozone injury.

Each tree was compared with itself from year to year using the paired t-test as reported by Miller and Elderman (4). The 1974 ozone injury scores were used as the basis for comparison with subsequent years.

RESULTS AND DISCUSSION

The five-year results from the trend plots are shown in Table 6.

TABLE 6. Results from ozone injury trend plots on the Sequoia National Forest, 1974 - 1978. (Means are shown with 95 percent confidence limits).

PLOT NAME	DATE DATA COLLECTED	NO.of LIVE TREES	PERCENT TREES w/ SYMPTOMS	MEAN OZONE RATING (FIDM Score)
Eshom Creek	27 Sep 74	52	100	2.0 ± 0.4
4800' (1460m)	2 Sep 75	52	85	1.8 ± 0.5
	21 Oct 76	52	81	2.1 ± 0.4
	31 Aug 77	52	90	2.1 ± 0.3
	12 Sep 78	52	92	1.7 ± 0.3
Pine Ridge	28 Aug 74	25	80	2.6 ± 0.5
4500' (1370m)	27 Aug 75	25	92	2.2 ± 0.6
	1 Dec 76	25	56	2.8 ± 0.5
	30 Aug 77	25	64	3.0 ± 0.4
	12 Sep 78	24	79	2.2 ± 0.5

On the Eshom Creek plot the FIDM score remained relatively unchanged from 1974 to 1978 at a Moderate-to-Severe injury level. The decrease in ozone scores between 1974 and 1978 was not significant ($P = 0.05$). This plot represents the most severe injury condition encountered on the entire ground survey of the two National Forests. Ozone injury on the Pine Ridge plot fluctuated

from year to year between 1974 and 1978 at a Slight-to-Moderate injury level. Scores in 1975 and 1978 did drop to more severe levels; however, these decreases were not significant when compared to the 1974 level of injury ($P = 0.05$). These increases in injury may have been caused by high ozone doses in preceeding years, but no ozone data are available to substantiate this.

Although these plots represent the most severe injury encountered during the ground survey, no continuous increase or decrease of ozone injury has occurred in the last five years. The ozone dose appears to be high enough to cause moderate injury to susceptible pines, but insufficient to produce rapid decline or death.

OZONE MONITORING

The FIDM Staff conducted short-term ozone monitoring at several sites on Sequoia National Forest and Sequoia National Park between August and October of 1974, and found ozone doses sufficient to cause injury to pines (7). In order to establish the season-long dose of ozone, monitoring was begun at Whitaker's Forest (5400 feet/1645 meters) in July of 1976, and has continued to the present. In 1977 monitors were placed at Park Ridge Lookout (7540 feet/2300 meters) from April through October, and at Mountain Home State Forest (5920 feet/1805 meters) from August through November. In addition, 1977 ozone data were obtained from the Fresno County Air Pollution Control District monitor at Shaver Lake (5600 feet/1705 meters).

Ozone monitoring sites are illustrated in Figure 3. Whitaker's Forest is approximately 50 miles (80 kilometers) due east of Fresno; Shaver Lake is 35 miles (56 kilometers) northwest, and Mountain Home is 35 miles southeast of Whitaker's. Park Ridge Lookout is two miles (3 kilometers) due north of Whitaker's Forest, on the highest ridge of the west face of the Sierra Nevada.

METHODS

Ozone concentrations were measured with Dasibi ozone monitors calibrated by the State of California Air Resources Board and maintained by the FIDM Staff. Ambient air samples were collected through Teflon tubing, with sample inlets located 20 to 26 feet (6-8 meters) above ground level. Span frequencies were set to compensate for elevation according to Air Resources Board specifications.

RESULTS AND DISCUSSION

Comparable data from Whitaker's Forest and from Sky Forest, which is at 5640 feet (1720 meters) elevation on the San Bernardino National Forest, show that ozone levels in the southern Sierra do not approach

the extremes recorded in southern California forests (Table 7.)

TABLE 7. Comparison of ozone concentrations in the San Bernardino National Forest (Sky Forest) with concentrations in the southern Sierra Nevada (Whitaker's Forest), June-September 1977. (Concentrations are expressed as maximum hourly averages and means of daily maximum hourly averages, and are shown as pphm, or parts per hundred million.)

	JUNE		JULY		AUGUST		SEPTEMBER	
LOCATION	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)
Sky Forest	32	20	30	22	33	19	24	14
Whitaker's Forest	14	10	15	11	14	11	13	9

The maximum hourly averages and the means of the daily maxima at Whitaker's were about one-half of those recorded at Sky Forest. The lower ozone dose in the southern Sierra corresponded to a similarly lower level of injury to pines.

The ozone levels recorded at Whitaker's during the summer were commonly reached at Shaver Lake and Mountain Home, along a 70 mile- (113 kilometer-) long portion of the Sierra front range (Table 8.) Initial discoveries of ozone symptoms in the Sequoia National Forest directly downwind from Fresno led us to expect ozone levels to be much higher at Whitaker's Forest than at other sites to the north and south. However, the similarity of daily maxima at these sites, as well as at the higher altitude of Park Ridge, suggests that the intrusion of injurious ozone levels into these mountains is an area-wide rather than a local phenomenon.

The Federal Standard for ozone (8 parts per hundred million for one hour per year) was exceeded almost daily at the four sites during a 22-day period for which comparable data were recorded (Figure 4). The means of the daily maximum hourly averages were nearly identical, and the patterns of day-to-day fluctuation in ozone levels were remarkably similar. During this period, ozone levels exceeded the Federal Standard at Mountain Home for about one-half the hours exceeded at Whitaker's while the Standard was exceeded at Shaver Lake and Park Ridge for an intermediate number of hours. Two points are

TABLE 8. Comparison of ozone concentrations at four sites in the southern Sierra Nevada, June-September 1977. (Concentrations are shown in parts per hundred million; data are not included for those months in which 85 percent or less of the hourly average concentrations were recorded.)

LOCATION	JUNE		JULY		AUGUST		SEPTEMBER	
	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)	MAX. HRLY. AVER. (pphm)	MEAN of MAX. HOURS (pphm)
Shaver Lk. Fresno Co.	11	8	13	9	15	11	12	8
Whitaker's Forest	14	10	15	11	14	11	13	9
Park Ridge Lookout	12	9	13	9	13	10	12	8
Mountain Home	--	--	--	--	13	10	12	8

important here: (1) the Federal Standard was exceeded at Whitaker's Forest for 42 percent of the total hours sampled from 4 to 25 August 1977; and, (2) Park Ridge Lookout, despite its location atop an exposed ridge, received a similarly large dose of ozone.

Figure 5 illustrates the hourly ozone levels at Whitaker's Forest on an especially adverse day. The ozone levels were at or above the Standard during all but one hour for the entire 24-hour period; frequent daily patterns such as this accounted for the large number of hours over the Standard during each summer month. For example, from June through August 1977, the Federal Standard was exceeded during 790 hours, or 36 percent of all hours, day and night.

Ozone concentrations at Whitaker's Forest in 1977 were generally higher than those in 1976. Between 16 July and 31 October, the number of hours over the Standard in 1977 was 85 percent greater than in 1976. Although this was nearly a two-fold increase in ozone dose from 1976 to 1977, this trend was based on two years' data only; we cannot say whether this was normal year-to-year fluctuation, or part of an upward trend in ozone levels.

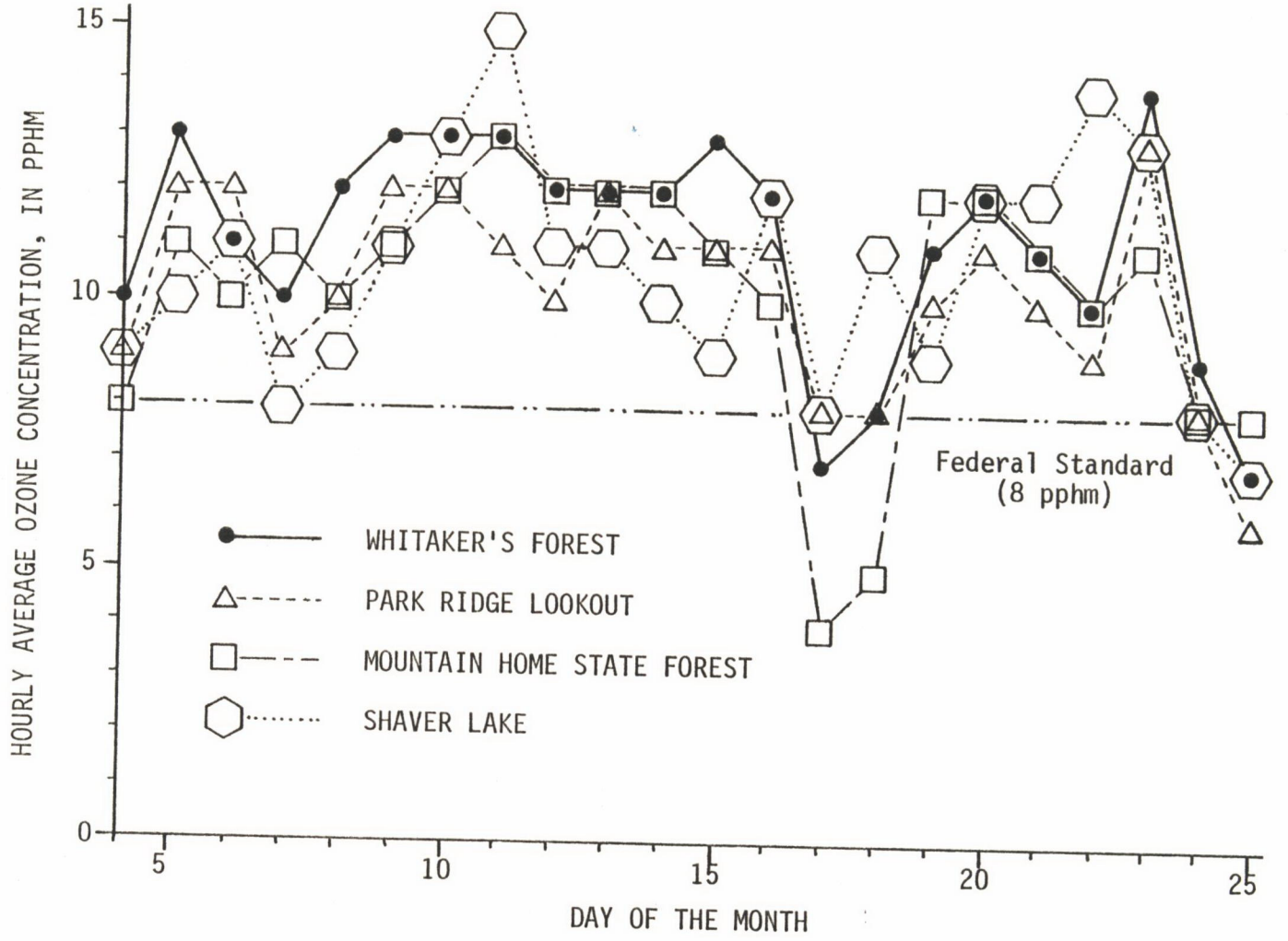

FIGURE 4. Comparison of daily maximum hourly average ozone concentrations at four sites in the southern Sierra Nevada, 4 - 25 August 1977.

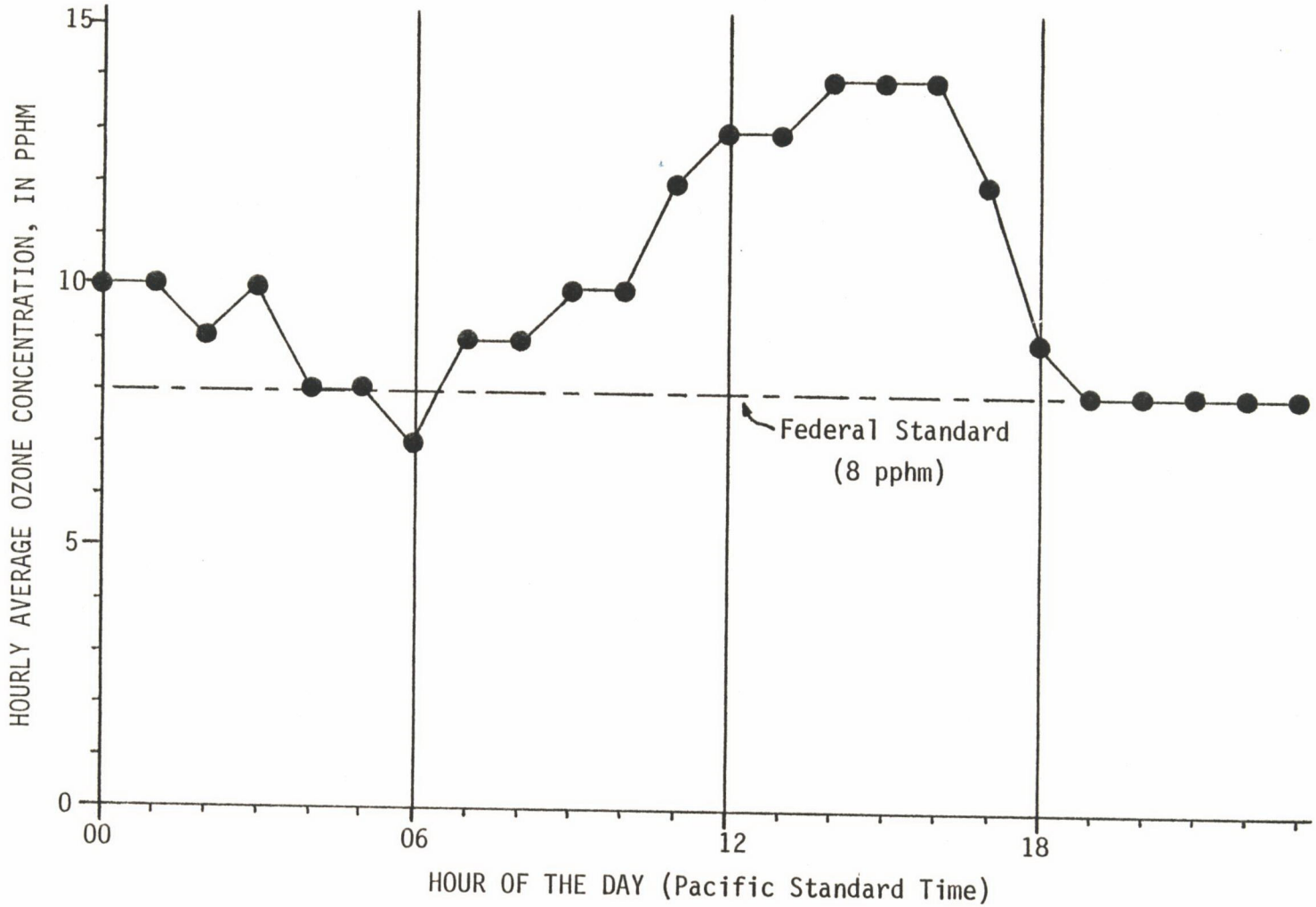

FIGURE 5. Pattern of hourly average ozone concentrations on an adverse day at Whitaker's Forest, 3 August 1977.

CONCLUSIONS

We conclude that, (1) ozone symptoms are common and wide-spread in much of the southern Sierra, but ozone is not causing moderate or worse injury on a forest-wide basis; (2) although few in number, localities with moderately-injured pines do exist; (3) the worst injury found was located on front range mountains adjacent to the San Joaquin Valley or along major river drainages; (4) ozone-sensitive trees will probably suffer continued injury as past seasonal ozone doses reoccur; (5) the level of injury has not consistently increased or decreased since 1974; (6) ozone concentrations sufficient to cause injury to pines can be measured from Shaver Lake south to Mountain Home State Forest.

Given the present levels of ozone and of ozone injury to pines at widely-scattered sites, and the possibility that ozone doses may increase, the present condition in these two National Forests appears to be one of great potential rather than actual damage.

RECOMMENDATIONS

The data gathered from the ground survey, the ozone monitoring, the trend plots, and information from other sources point to the need for a forest-wide Pest Damage Inventory (PDI) on the Sierra and Sequoia National Forests. A PDI would identify the causes and amounts of current tree mortality for an entire forest. For future purposes this baseline data would enable us to estimate what proportion of the total mortality, if any, is attributable to or associated with ozone. The ultimate value of this information would be to provide forest management recommendations or alternatives. In addition, ozone monitoring and trend plot studies should be continued in order to provide annual estimates of the impact of air pollution in the southern Sierra. Because the present trend plots are in a small area and represent an extreme in ozone injury, we recommend that additional plots be established. The new plots should be positioned throughout both National Forests and include a variety of sites, stand characteristics, and ozone exposures.

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